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A Foliar Diagnosis Study of the Nutrition of Greenhouse Tomatoes in Relation to the Incidence of a Disease*

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THE mechanism of resistance to attack by an organism is not known. It is possible that in some way at present unknown the plant juices may inhibit the organism; on the other hand, in many cases the evidence points to the inability of the organism to find the proper nutritive conditions in the particular environment.

Species differ in their resistance to attack by a specific organism. It has been suggested that certain morphological peculiarities may result in an "aptitude" for a particular organism and failing such "aptitude" no cause can be sufficient to produce infection. It must not be forgotten, however, that morphology is merely a consequence of the physiological processes involved.

Although diseases resulting apparently from deficiencies of any one or more of the principal nutritive mineral elements and also from certain trace elements have been described in the literature, the systematic determination of such deficiencies has awaited the development of a simple, sensitive, and convenient method of unimpeachable validity.

To determine the relations of fertilizer treatment and the resulting plant nutrition to variation in the incidence of disease in crops growing on soils under ordinary commercial conditions, whether in the field or in the greenhouse, requires that analyses of plant nutrition be made under such conditions. Results of studies on plants grown in nutrient solutions or in sterile media, inoculated with pure cultures of organisms, obviously would be inapplicable.

The method of foliar diagnosis *(3*, *7*, *8*, and *11)* has been shown to satisfy these requirements, insofar as the relation of nutrition to soil, fertilizer treatment, climatic conditions, and the resulting crop yields is concerned. By means of the relatively easy method of a comparison of the intensity of nutrition and equilibrium conditions between the dominant nutritive elements in morphologically homologous leaves of diseased and healthy plants, foliar diagnosis offers a means of ascertaining the relationship of the visible manifestations of disease to nutrition, but without necessarily attempting to indicate whether the visible manifestations are a cause or merely an effect.

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If resistance to infection is associated with a particular gene, this fact would indicate the need for exploring the relationship of nutrition to genetic structure. The application of foliar diagnosis to genetic studies would, therefore, be a promising field of research.

The experimental basis establishing the validity of the method together with a definition of terms and concepts used in the method have already been published *(3*, 7, and *8)*. In the present report the application of the method to a diagnosis of the nutritional condition of the leaves of tomato plants in various stages of breakdown from disease of which the symptoms were typical of infection by *Fusarium lycopersici* Sacc. is examined.

MATERIALS AND METHODS

The three infected plots formed a part of the differentially fertilized greenhouse tomato experiments with and without manure described previously *(4, 11)*. For the convenience of the reader, the plots and treatments may be outlined briefly: the plots were 5¾ feet wide and 8 feet long, and each contained 3 rows of 4 plants each, planted approximately 2 feet apart in either direction. Two rows of 10 plots each were contained in each of 2 large beds. Both plots in each pair located side by side in a bed received the same commercial fertilizer treatment, but only one received manure. Plots were separated by means of fir boards 12 inches wide and 1 inch thick set edgewise into the soil so that a part of the board about 2½ inches wide extended above the soil surface.

The soil of the experiment was a composted clay loam about 14 inches deep, with a clay loam subsoil. It was steam pasteurized once each year, after manure had been applied; steam was introduced through lines of 4-inch drain tile 27 inches apart, which provided drainage at other times.

Each treatment was applied to two different plots, but in most couplets nutrition differed considerably between the two, as indicated by foliar diagnosis studies to be published elsewhere *(12)*.

FERTILIZER TREATMENTS

The diseased plants investigated in the present report were those grown on: Plot 15R which received a complete fertilizer; Plot 16L which received nitrate plus phosphate only; and plot 20L which received phosphate plus potash only, all without manure additions.

Plot 15R received 1.15 pounds of sodium nitrate, 1.38 pounds of superphosphate, and 0.17 pound of muriate of potash. These quantities are equivalent to 42.1 grams of N, 125.2 grams of P_2O_5, and 43.1 grams of K_2O per plot, or to 500 pounds of $NaNO_3$, 1250 pounds of superphosphate, and 350 pounds of muriate of potash

per acre. Plot 16L received half the amount of sodium nitrate applied to plot 15R, and the same quantity of superphosphate. Plot 20L received the same quantities of phosphate and muriate of potash applied to plot 15R.

The comparison was made with vigorous, healthy plants grown on plot 8L, which received a complete fertilizer consisting of the foregoing amounts of superphosphate and muriate of potash plus unit amounts of sodium nitrate, 0.575 pound per plot applied biweekly, together with a dressing of 110 pounds of manure to the plot. This quantity of manure contained 422.1 grams of N, 274.9 grams of P_2O_5, and 345.8 grams of K_2O.

SYMPTOMS OF INFECTION

During the first week in June some of the plants growing on plots 15R, 16L, and 20L showed the following symptoms, which are characteristic of the disease caused by *Fusarium lycopersici* Sacc.: Lower leaves turned yellow in color, and gradually died; upper, younger leaves wilted during sunny portions of the day, even when the soil was well supplied with water; and vascular tissues of the dying lower leaves and of the lower part of the stem were necrotic, and were grayish brown in color. Later, about June 20, severely diseased plants died; the last parts of the plant surviving were the stem terminal and the youngest leaves.

The disease was observed first on certain plots which received no manure or potash fertilizer, among them 16L, and its severity was greatest on these plots. Nearly all plants on these plots were infected, and all of the plants on 16L were dead before the end of the spring crop season. Plants on certain other plots either did not show any symptoms at all throughout the season, as on 8L, or developed only mild to intermediate symptoms, as on 20L. The extent of disease incidence appeared to be characteristic of the different plots. The plots studied were chosen to represent distinct degrees in the incidence of the disease among a considerable range.

It is highly probable that all of the plants in the different plots were about equally exposed to infection by the causal organism. No precautions were taken to prevent transfer of soil particles from one plot to another on tillage implements, watering hoses, or on shoes of workmen, or of juices of plants from one to another in pruning. From the fact that the incidence of the disease was earlier and the severity much greater in some plants than in others, it is evident that specificity of the disease was higher for certain individual plants than for others.

The cause of the disease was not identified in this particular instance; in this study, attention was paid to the relationship of the nutrition of the plants to the development of disease symptoms,

rather than to the infection of plants by the causal organism. It should be noted that identification beyond question of the cause of a disease occurring on a crop growing in soil under commercial conditions is very difficult, because all other conditions or agencies which conceivably might bring about similar symptoms must be eliminated.

SAMPLING LEAVES FOR ANALYSIS

By June 10 all leaves below the twelfth from the base on plots 15R, 16L, and 20L had senesced, chlorophyll degeneration being complete. On this date, June 10, the sixteenth leaf was taken from (1) plants on the above plots which showed no visible manifestation of disease, (2) plants with slight symptoms, and (3) plants severely diseased. At the same time the sixteenth leaf was collected also from the vigorous, healthy plants on plot 8L. All leaves taken as samples were sound and functioning, whether the plants which they represented were healthy or diseased.

The leaves were dried at 100° Centigrade and ground to a fine powder in a Wiley mill.

ANALYTICAL METHODS

The analytical methods used were those prescribed by the Association of Official Agricultural Chemists *(1)* and were such as gave the total amounts of the elements irrespective of the form in which the elements were present in the leaf *(3)*.

Nitrogen was determined by the Kjeldahl-Gunning method to include the nitrogen of nitrates, phosphoric acid by Richards and Godden's modification *(2)* of the Pemberton-Neumann method, and potash by the Lindo-Gladden method. Lime (Calcium) was determined by titration of the oxalate with potassium permanganate, and magnesia was measured gravimetrically as the pyrophosphate.

PRESENTATION OF RESULTS

YIELDS OF FRUIT AND CONDITION OF PLANTS

Plot treatments, yields, and remarks on the condition of the plants examined are given in table 1.

Table 1.—Yields from the healthy and diseased plots.

Plot	Treatment	No. of Fruits	Pounds of Fruit	Condition of Plants
8L	(RN)PK and manure	391	120.5	All vigorous and healthy
20L	PK (No manure)	335	98.8	Some indicated slight infection
15R	(2N) PK (No manure)	154	34.1	Many severely diseased
16L	NP (No manure)	149	30.9	Many severely diseased

Table 2.—Percentages of N, P_2O_5, K_2O, CaO, and MgO in dried foliage from plants growing on plots with different treatments, whether healthy or exhibiting wilt symptoms of different severity, together with the respective milligram-equivalent values and the composition of the NPK-units.

CONDITION OF PLANTS	MINERAL CONTENT OF DRIED FOLIAGE						MILLIGRAM EQUIVALENT				COMPOSITION OF THE NPK-UNIT		
	N (M_x)	P_2O_5 (M_y)	K_2O (M_z)	$N+P_2O_5+K_2O$ (s)	CaO	MgO	N (E_x)	P_2O_5 (E_y)	K_2O (E_z)	$E_x+E_y+E_z$ (S)	X $\left(100\frac{E_x}{S}\right)$	Y $\left(100\frac{E_y}{S}\right)$	Z $\left(100\frac{E_z}{S}\right)$
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*							
	(RN)PK + manure; Plot 8L; Yield 120.5 pounds												
All plants healthy	3.58	1.64	2.68	7.90	7.60	1.93	255.6	69.3	57.1	382.0	66.9	18.2	14.9
	PK (No manure); Plot 20L; Yield 98.8 pounds												
No visible manifestations	2.56	1.13	1.66	5.35	11.06	2.19	132.8	47.6	35.4	265.8	68.8	17.9	13.3
Slight symptoms	2.10	0.69	1.16	3.95	3.73	1.03	149.9	29.3	24.8	204.0	73.5	14.4	12.1
Severely diseased	None severely diseased												
	(2N)PK (No manure); Plot 15R; Yield 34.1 pounds												
No visible manifestations	2.82	0.86	1.25	4.93	7.84	1.81	201.3	36.5	26.6	264.4	76.2	13.8	10.0
Slight symptoms	2.48	0.66	0.83	3.97	6.25	2.04	177.1	27.8	17.6	222.5	79.6	12.5	7.9
Severely diseased	2.20	0.56	1.45	4.21	2.80	0.57	157.1	23.4	30.9	211.4	74.3	11.1	14.6
	NP (No manure); Plot 16L; Yield 30.9 pounds												
No visible manifestations	3.20	3.34	1.01	7.55	9.99	4.10	228.5	141.3	21.5	391.3	58.4	36.1	5.5
Slight symptoms	2.38	2.70	0.65	5.73	8.68	2.53	169.9	114.2	13.8	297.9	57.0	38.3	4.6
Severely diseased	2.48	1.87	0.56	4.91	9.10	3.38	177.1	79.2	12.0	268.3	66.0	29.5	4.5

ANALYTICAL DATA

Table 2 on the preceding page shows the percentages of nitrogen, phosphoric acid, potash, lime, and magnesia in the dried material from the leaves of various types of plants together with the intensities of nutrition with respect to the plastic elements, nitrogen, phosphoric acid, and potash, and their physiological relations as indicated by the composition of the NPK-unit. Table 3 shows the values of the CaMgK units *(3)*. Figure 1, page 8, shows the value of the NPK-units and figure 2, page 9, that of the CaMgK-units in trilinear coordinates.

The coordinate points marked by a cross (+) in figures 1, 2, and 3 show the positions of the NPK-units and the CaMgK-units, respectively, of the morphologically homologous leaves from the vigorous and healthy plants growing on plot 8L.

Table 3.—The CaMgK-unit values of the dried foliage from healthy and diseased plants.

Condition of Plants	Mineral Content of Dried Foliage: CaO (M_x)	MgO (M_y)	K_2O (M_z)	Milligram Equivalent: CaO (E_x)	MgO (E_y)	K_2O (E_z)	$E_x+E_y+E_z$ (S_1)	Composition of CaMgK-unit: $\left(100\frac{E_x}{S_1}\right)$	$\left(100\frac{E_y}{S_1}\right)$	$\left(100\frac{E_z}{S_1}\right)$
	per cent	*per cent*	*per cent*							
				(RN)PK + manure; Plot 8L						
All healthy plants	7.60	1.93	2.68	271.3	96.2	57.1	424.6	63.9	22.6	13.5
				PK (No manure); Plot 20L						
No visible symptoms	11.06	2.19	1.66	394.8	109.2	35.4	539.4	73.2	20.2	6.6
Slight symptoms	3.73	1.03	1.16	133.3	51.0	24.8	209.1	63.8	24.4	11.8
Severely diseased										
				(2N)PK (No manure); Plot 15R						
No visible symptoms	7.84	1.81	1.25	279.9	90.1	26.5	396.5	70.6	22.7	6.7
Slight symptoms	6.25	2.04	0.83	223.2	101.4	17.6	342.2	65.2	29.6	5.2
Severely diseased	2.80	0.57	1.45	100.0	28.2	30.9	159.1	62.8	17.7	19.5
				NP (No manure); Plot 16L						
No visible symptoms	9.99	4.10	1.01	356.5	204.3	21.6	582.4	61.2	35.1	3.7
Slight symptoms	8.68	2.53	0.65	309.9	126.2	13.8	449.9	68.9	28.0	3.1
Severely diseased	9.10	3.38	0.56	324.9	168.3	12.0	505.2	64.3	33.3	2.4

CALCULATION OF RESULTS

The derivation of these units has already been explained *(3, 8, 9)*. As an illustration of the method of calculation, the values of the sixteenth leaf of the NP plot, 16L, which on June 10 showed no visible signs of infection, are given. Analysis of the leaf indicates: N = 3.2 per cent; P_2O_5 = 3.34 per cent; K_2O = 1.01 per cent.

The sum of the percentages of N, P_2O_5, and K_2O, or the intensity of nutrition is:

$$s = 3.20 + 3.34 + 1.01 = 7.55$$

The values in milligram equivalents shown in columns 9, 10, and 11 of table 2 are calculated by the use of the factors 71.4 for N, 42.3 for P_2O_5, and 21.3 for K_2O. The derivation of the N factor, for example, is:

14 grams N = 1 gram equivalent
1 gram N = .0714 gram equivalent
= .0714 x 1000 or 71.4 milligram equivalents

Then:

$$E_x = 3.20 \times 71.4 = 228.5$$
$$E_y = 3.34 \times 42.3 = 141.3$$
$$E_z = 1.01 \times 21.3 = 21.5$$
$$S = E_x + E_y + E_z = 391.3$$
$$X = \frac{100 \times 228.5}{391.3} = 58.4$$
$$Y = \frac{100 \times 141.3}{391.3} = 36.1$$
$$Z = \frac{100 \times 21.5}{391.3} = 5.5$$

The value of the NPK-unit, then, is 58.4 : 36.1 : 5.5; it shows the proportion of the milligram equivalent total which is constituted by the milligram equivalent content of each element in the dried foliage.

The method of representing the NPK-units graphically in trilinear coordinates has been described and discussed *(10)*. For the purpose of this report, it may be explained that, in an equilateral triangle, the sum of the distances from any point within the triangle to the three sides is constant, and equal to the altitude of the triangle. In an equilateral triangle with an altitude of 100, therefore, any value of the NPK- or CaMgK-unit may be represented by a single point, since the sum of the three proportionate quantities always equals 100; changes in these units appear as displacements of the coordinate points representing the units, and the direction of the displacements indicate the nature of the change.

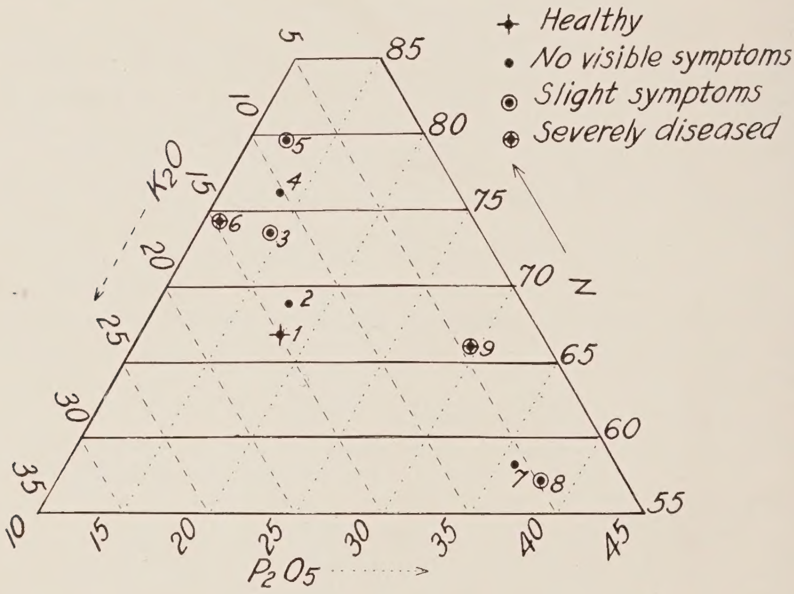

Fig. 1.—NPK-units of sixteenth leaves from the bases of healthy plants and those exhibiting Fusarium wilt symptoms of different severity, shown in trilinear coordinates. Number 1 in the diagram designates plot 8L, (RN) PK + manure in which the plants were all healthy; numbers 2 and 3 designate plot 20L, PK in which plants exhibited no visible symptoms and slight symptoms of disease, respectively; numbers 4, 5, and 6, designate plot 15R, (2N)PK in which plants exhibited no visible symptoms, slight symptoms, and severe symptoms of disease, respectively; and numbers 7, 8, and 9 designate plot 16L, NP, in which the plants exhibited no visible symptoms, slight symptoms, and severe symptoms of disease, respectively.

The coordinate points numbered 2, 4, and 7 in figure 1 are the positions of the coordinate points of the sixteenth leaf from plants growing on the PK plot, 20L, the (2N)PK plot, 15R, and the NP plot, 16L, respectively which on June 10 showed no visible manifestations of disease.

The coordinate points numbered 3, 5, and 8, in figure 1 represent the positions of the NPK-units of leaves from those plants growing on the above mentioned plots which showed at this date visible evidence of slight infection.

The coordinate points marked 6 and 9 in figure 1 are the positions of the coordinate points of the NPK-units from plants growing on the (2N)PK plot, 15R, and the NP plot, 16L, respectively, and which showed visible evidence on June 10 of severe infection.

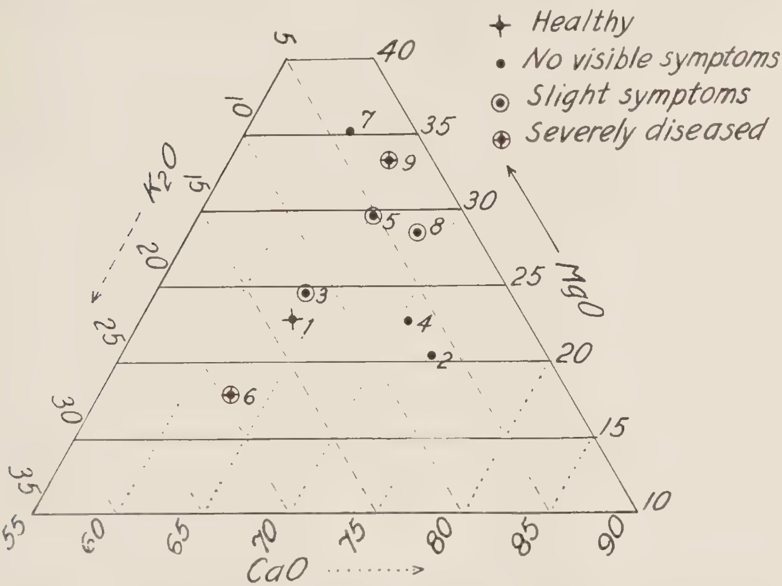

Fig. 2.—CaMgK-units of sixteenth leaves from the bases of healthy plants and those exhibiting Fusarium wilt symptoms of different severity, shown in trilinear coordinates. Number 1 in the diagram designates plot 8L, (RN) PK + manure, in which plants were all healthy; numbers 2 and 3 designate plot 20L, PK, in which plants exhibited no visible symptoms and slight symptoms of disease, respectively; numbers 4, 5, and 6 designate plot 15R, (2N) PK, in which plants exhibited no visible symptoms, slight symptoms, and severe symptoms of disease, respectively; and numbers 7, 8, and 9 designate plot 16L, NP, in which plants exhibited no visible symptoms, slight symptoms, and severe symptoms of disease, respectively.

DISCUSSION OF RESULTS

THE COMMON PROPERTY ASSOCIATED WITH THE PRESENCE OF DISEASE SYMPTOMS

Only one characteristic was common to all plants growing on plots in which disease appeared: The *intensity of nutrition* with respect to the plastic (labile) elements nitrogen, phosphoric acid, and potash in leaves from plants showing no visible symptoms of disease as well as from those giving visible evidence of infection was less than that of morphologically homologous leaves of the vigorous plants of plot 8L, none of which was diseased.

Again, the *intensity of nutrition* of leaves from plants on plots 20L, 15R, and 16L, which showed visible manifestations of disease, was less than that of morphologically homologous leaves from plants on the respective plots which had no visible evidence of disease on this date, June 10.

Furthermore, in two plots, PK, plot 20L and NP, plot 16L, the intensity was lower in the plants showing severe symptoms of disease than in morphologically homologous leaves of plants of the respective plots which showed less marked symptoms. In (2N)PK, plot 15R, however, little difference occurred in the intensities of the severely and slightly diseased plants.

The intensity of *nutrition*, therefore is an index that quantitatively the nutrition with respect to the plastic elements was insufficient in leaves from all types of plants growing on those plots in which many of the plants gave visible evidence of infection.

QUALITATIVE DIFFERENCES IN THE MODE OF NUTRITION AMONG PLANTS SUBJECT TO THE DISEASE

Qualitatively, however, considerable difference existed in the nutrition of the plants from these diseased plots. These differences will be considered first collectively and then separately.

THE GENERAL CHARACTERS OF THE DISEQUILIBRIUM BETWEEN N-P_2O_5-K_2O

Figure 1 shows that the coordinate points of all types of leaves from the plots having diseased plants are displaced further from the apex $K_2O = 100$ than that of plot 8L on which no disease appeared. It is to be noticed that coordinate points 7, 8, and 9 of the plot 16L which received no potash applications are further removed from this apex than are 4, 5, and 6 of plot 15R and 2 and 3 of plot 20L which received muriate of potash in the fertilizer.

Relative to displacements from the summit apex $N = 100$ and toward the right base apex $P_2O_5 = 100$, sharper differences appear in the mode of nutrition of (2N)PK, plot 15R, and PK, plot 20L, on the one hand and NP, plot 16L, on the other. The coordinate points of leaves from all types of plants of the former two plots, 2 and 3, and 4, 5, and 6, respectively, are displaced relative to that of the healthy plants of 1, plot 8L, further towards the summit apex $N = 100$ and away from the right base apex $P_2O_5 = 100$; whereas the coordinate points, 7, 8, and 9, of leaves from all types of plants from plot 16L show reverse relationships, the displacement in this case being towards the right base apex and away from the summit apex.

The latter relationships suggest that, although certain plants appeared to be healthy while others growing on the same plots exhibited disease symptoms, the former were, in fact, either already infected on June 10 or in a condition of susceptibility. Later developments confirmed this indication; as previously stated, all plants on plot 16L finally became diseased, and died before the end of the season.

The PK Plot, 20L.—The yield of fruit from plot 20L was next highest to that from the vigorous and healthy plants on plot 8L which received complete fertilizer with manure.

None of the plants growing on PK, plot 20L, showed evidence at this date of severe infection; many of the plants did, however, show slight symptoms of disease. Accordingly, it would be expected that the N-P_2O_5-K_2O equilibrium would not be very remote from that of the vigorous and healthy plants from plot 8L which had no disease. This is in fact the case. Figure 1 shows that the coordinate points, 2 and 3, of PK, plot 20L, are nearer to that of the optimum, than any of the others. Moreover, the coordinate point, 2, of the leaves from plants showing no visible symptoms of disease at this date is nearer the optimum than 3, that of the slightly diseased plants of this plot, No. 20L.

On the other hand examination of figure 2 showing the position of coordinate points 2 and 3 of the CaO-MgO-K_2O equilibrium *(6,* and *9)* reveals no relationship to the incidence of disease on this plot.

The (2N)PK Plot, 15R.—The yield of fruit from (2N)PK, plot 15R, was but slightly greater than that of the lowest yielding, NP, plot 16L.

Figure 1 indicates that the coordinate points representing the N-P_2O_5-K_2O equilibrium of the "severely diseased" plants from plot 15R and those showing no visible symptoms, 6 and 4, respectively, are almost equidistant from 1, that of the uninfected plants of plot 8L, and that the coordinate point, 5, of the "slightly diseased" plants is further removed.

The intensity of nutrition, as already stated, of leaves from all types of plants on this and the other diseased plots was lower than that of the vigorous, healthy plants of plot 8L. But apart from this fact, the displacement of the NPK-units measured *quantitatively* was insufficient to explain without further analysis the nature of the disequilibrium (if any) between N-P_2O_5-K_2O among the leaves from the various types of plants of plot 15R. But if, physiologically, the magnitudes for nitrogen, phosphoric acid, and potash in the NPK-unit do not have the same values as indicated by differences in *direction* of the displacements, then proximity alone of a coordinate point to the optimum might not be sufficient to indicate the nature of the disequilibrium.

Viewing the positions of the various coordinate points from this angle, it is noted that the NPK-unit of the "severely diseased" plants of plot 15R is further displaced away from the apex $P_2O_5 = 100$ than are the others, and the displacement is greater,

the more severe the disease symptoms. The progress of the disease then in this particular plot is indicated by a progressive decrease in the proportion of P_2O_5 in the composition of the NPK-unit, but a more important factor here is the CaO-MgO-K_2O equilibrium, 4, 5, and 6 in figure 2, which shows that the progress of the disease is coincident also with a large progressive decrease in the quota part of calcium in the composition of the CaMgK-unit.

The NP Plot 16L.—This was the lowest yielding plot studied.

Figure 1 shows that the coordinate points of all types of leaves, 7, 8, and 9, are displaced further away from the left base apex $K_2O = 100$ than are any of the others and that, moreover, the displacement is progressively greater with increase in the severity of the disease symptoms.

The same holds true for the equilibrium between CaO-MgO-K_2O, figure 2: the more marked the symptoms the further displaced is the point from the apex $K_2O = 100$. In these plants, consequently, the intensity of nutrition is too low, and potash is too low in relation to nitrogen and phosphoric acid, and also to lime and magnesia.

THE EQUILIBRIUM BETWEEN ANY TWO ELEMENTS

We have noted that in the case of the plants growing on plot 15R, that the *direction* of the displacement may be as important as the magnitude of the displacement in the N-P_2O_5-K_2O equilibrium. The direction of the displacement is readily examined from a consideration of the ratios between two entities.

In table 4 are shown the ratios of N : P_2O_5, P_2O_5 : K_2O, N : K_2O, CaO : MgO, MgO : K_2O, and CaO : K_2O in the NPK-units and the CaMgK-units. The traditional way is to express the values of these physiological relationships between any two elements as ratios between the percentage values in the plant material considered. This base of reference is open to the criticism that reactions in the leaf are between chemically equivalent quantities of the entities or elements considered and not between percentage values.

It is of interest to note in what way the relationship between two of these entities shows progressive changes with increase in the symptoms of disease of the plants growing on the various plots.

In the leaves of (2N)PK, plot 15R, it is only the N : P_2O_5 ratio that changes progressively with increase in the severity of the disease. But between the leaves from plants which on June 10 showed no visible evidence of infection and those from "severely diseased" plants there is a sharp decrease in the values of P_2O_5:K_2O, N : K_2O, MgO : K_2O, and CaO : K_2O.

On the other hand, in the plot which received no potash fertilizer, NP, No. 16L, the progress of the disease is marked by a sharp and progressive rise in the values for N:K_2O, MgO:K_2O, and CaO:K_2O.

Table 4.—The ratios between any two of the plastic elements and also between the bases.

CONDITION OF PLANTS	Ratio in the NPK-unit $N:P_2O_5$	$P_2O_5:K_2O$	$N:K_2O$	Ratio in the CaMgK-unit $CaO:MgO$	$MgO:K_2O$	$CaO:K_2O$
			(RN)PK manure; Plot 8L			
All healthy	3.79	1.21	4.48	2.80	1.71	4.80
			PK; Plot 20L			
No visible symptoms	3.83	1.36	5.16	3.13	3.12	11.27
Slight symptoms	5.11	1.26	6.07	2.60	2.08	5.39
			(2N)PK; Plot 15R			
No visible symptoms	5.52	1.36	7.55	3.11	3.39	10.53
Slight symptoms	6.56	1.42	10.06	2.20	5.76	12.78
Severely diseased	6.71	0.77	5.07	3.50	0.90	3.21
			NP; Plot 16L			
No visible symptoms	1.59	6.53	10.08	1.74	9.48	16.57
Slight symptoms	1.48	8.28	12.32	2.39	9.35	22.43
Severely diseased	2.23	6.57	14.80	1.93	13.87	26.79

SUSCEPTIBILITY TO INFECTION IN RELATION TO THE MODE OF NUTRITION

It has already been pointed out that certain evidence suggests that although some of the plants from plots that had diseased plants showed on June 10 no visible symptoms of disease, they were actually then infected or at least in a condition of susceptibility to infection.

This conclusion is supported by an examination of the mean values for the intensities of nutrition and of the mean NPK-units *(3)* of the fifth leaf from the base taken on April 5, April 29, and May 27, during which period no outward manifestations of disease appeared on any of the plots. These mean values together with the ratios between any two of them are given in table 5, and are shown graphically in trilinear coordinates in figure 3.

Table 5.—Comparison of the mean value of the intensities and mean value of the composition of the NPK-units of the fifth leaf taken on April 5, April 29, and May 27 from plants which remained healthy throughout the season and of those which later became diseased.

PLOT	TREATMENT	INTENSITY (Mean)	COMPOSITION OF NPK-UNIT (Mean values)	$N:P_2O_5$	$P_2O_5:K_2O$	$N:K_2O$
8L	(RN)PK and manure	7.83	71.2 : 13.9 : 14.9	5.13	0.93	4.77
20L	PK (No manure)	5.71	61.9 : 27.2 : 10.9	2.31	2.50	5.71
15R	(2N)PK (No manure)	5.80	74.4 : 16.0 : 9.6	4.65	1.65	7.71
16L	NP (No manure)	6.12	67.4 : 27.4 : 5.2	2.46	5.23	12.88

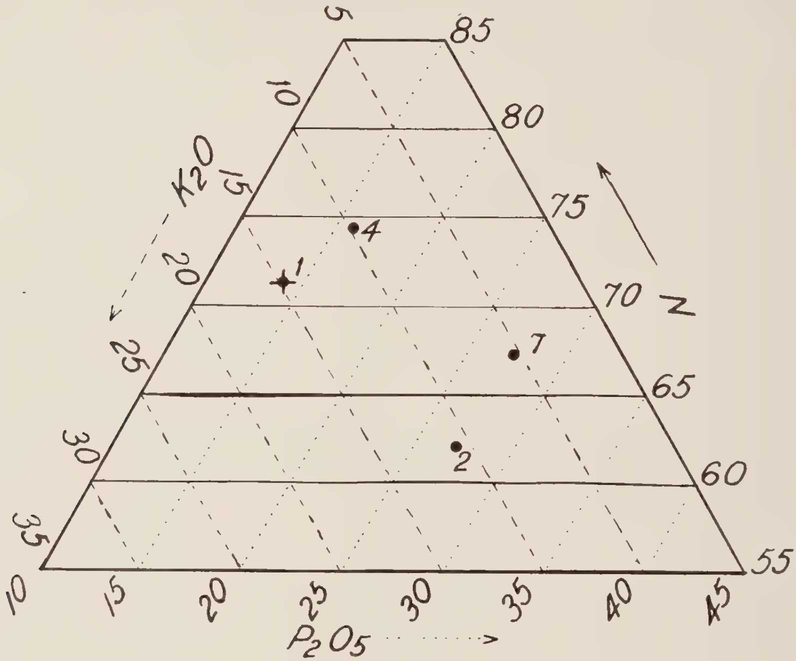

Fig. 3.—Mean NPK-units of fifth leaves from the base of plants sampled from April 5 to May 27, on a plot of which all plants remained healthy throughout the season, and on others of which plants later developed Fusarium wilt symptoms of different severity, shown in trilinear coordinates. Number 1 in the diagram designates plot 8L, (RN) PK + manure, plants from which were healthy throughout season; number 2 designates plot 20L, PK, plants from which later were slightly diseased; number 4 designates plot 15R, (2N) PK, plants from which later were moderately diseased; and number 7 designates plot 16L, NP, plants from which later were seriously diseased.

These values for the fifth leaf from the base are not comparable in magnitude with the values of the sixteenth leaf taken on June 10. Nevertheless, they may be examined to determine the kind of relationships expressed.

Comparison of tables 2 and 5 and of figures 1 and 3 shows that the plants on plots which later had some plants that became diseased have lower N : P_2O_5 and higher P_2O_5 : K_2O and N : K_2O ratios than those of plot 8L, none of which showed any symptoms of disease. The direction of the displacement is in all cases away from the left base apex, $K_2O = 100$ and towards the right base apex, $P_2O_5 = 100$.

The earliest date at which disequilibrium could have been recognized.—If susceptibility is related to the mode of nutrition as the evidence in these experiments would indicate, it is important to know how early in the growth period it would be possible to recognize a lack of nutritional equilibrium. The answer is given in table 6, which shows that compared with the healthy plants of plot 8L, 27 days after the plants were set in the beds, the others had too low intensity, too high $N : K_2O$, too high $P_2O_5 : K_2O$, and with one exception, too low $N : P_2O_5$ ratios.

Table 6.—The composition of the NPK-units of the fifth leaf on April 5 of plants which remained healthy compared with those which later became diseased.

Plot	Treatment	Intensity	Composition of NPK-unit	$N:P_2O_5$	$P_2O_5:K_2O$	$N:K_2O$
8L	(RN)PK and manure	8.94	73.8 : 11.5 : 14.7	6.45	9.78	5.02
20L	PK (No manure)	7.17	71.7 : 16.1 : 12.2	4.46	1.31	5.87
15R	(2N)PK (No manure)	7.68	78.5 : 11.2 : 10.3	6.96	1.10	7.63
16L	NP (No manure)	7.05	78.6 : 15.4 : 6.0	5.09	2.57	13.09

SUMMARY

In an experiment with differentially fertilized tomatoes grown under greenhouse conditions, plants on certain plots which received different combinations of commercial fertilizers without manure additions showed more or less marked symptoms of breakdown characteristic of infection by *Fusarium lycopersici* Sacc., whereas plants growing on other plots, notably those which received manure in addition to commercial fertilizers, did not become diseased.

The foliar diagnoses of morphologically homologous leaves from plots having diseased plants of three types, (1) severely diseased, (2) with slight symptoms, and (3) those which showed no visible symptoms of infection at this date, June 10, were compared with those of morphologically homologous leaves from vigorous and healthy plants from a plot treated with tertiary combinations of commercial fertilizers together with heavy applications of rotted manure, none of the plants of which showed any evidence of disease.

The intensity of nutrition with respect to the plastic elements, nitrogen, phosphoric acid, and potash, was less in leaves from all types of plants from plots having diseased plants than in those from the plot on which all were vigorous and healthy. The lower the intensity of nutrition, moreover, the greater was the onslaught of the disease.

The physiological relationships between the plastic elements and also between the bases, lime, magnesia, and potash, are shown in

trilinear coordinates by means of the values for the composition of the NPK-units and CaMgK-units, respectively, in the sixteenth leaf.

The coordinate points of the leaves of plants growing on two plots, one of which received muriate of potash together with sodium nitrate and superphosphate and the other, muriate of potash together with superphosphate but without sodium nitrate were displaced relative to the coordinate point of the vigorous, healthy plants which received tertiary combinations of fertilizer together with manure and none of which became diseased; the displacement was higher towards the apex $N = 100$ and further away from the right base apex $P_2O_5 = 100$ and also from the left base apex $K_2O = 100$, indicating higher values for nitrogen, and lower values for P_2O_5 and K_2O in the NPK-unit.

In the other diseased plot which received only sodium nitrate and superphosphate without muriate of potash, the coordinate points of leaves from all types of plants were displaced relative to the coordinate point of the vigorous, healthy plants from the plot which received all three elements together with manure, further away from the summit apex $N = 100$ and also from the left base apex $K_2O = 100$, but towards the right base apex $P_2O_5 = 100$, indicating lower values for nitrogen and also for potash, but higher values for phosphoric acid in the composition of the NPK-unit.

In one case, that of leaves from badly diseased plants of the plot which received all three elements without manure, the progress of the disease resulted in a progressive decrease in the calcium of the CaMgK-unit.

Evidence that susceptibility to disease in these plants was related principally to nutritional disequilibrium between the plastic elements, nitrogen, phosphoric acid, and potash, is given.

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